RECOMMENDATIONS FOR EXPERIMENTAL WORK ON SANDWICH CONSTRUCTION

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ON SANDWICH CONSTRUCTION

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

1

RECOMMENDATIONS FOR EXPERIMENTAL WORK ON SANDWICH CONSTRUCTION

1.0 INTRODUCTION

One of the requirements of Contract NAS 9-8244 (Manual for Structural Stability Analysis of Sandwich Plates and Shells) was the preparation of a list of recommendations for additional experimental work to cover those sandwich configurations where a definite data need was pinpointed during the preparation of the manual. This list of recommendations was to cover not only those areas where no data was found but also those where "soft" spots existed in that available.

Obviously, in preparing a list of recommendations of this type a number of factors must be taken into account. Some of these are the potential need for the specialized configuration under a range of loading conditions, availability of adequate substitute constructions, and penalties involved in using the substitute construction. These items are noted here in order to develop a general background and set of rules to be applied during the definition of the recommendations.

As a first restriction, recommendations to be made in this report will limit themselves to structural configurations and loading conditions generally found in aerospace vehicles and systems. Thus, the sandwich configurations and general loading conditions investigated in the manual will provide the framework for the development of these recommendations. While there are an infinite number of configurations possible, any which have contours more complex than those in the manual would have the combined drawbacks of being hard and costly to fabricate as well as being poor load carrying systems structurally because of angularity or radical curvature.

The other items which would normally require consideration in the development of these recommendations such as the availability of adequate substitute constructions and the penalties involved in using these substitute constructions vary with the potential uses and vehicles involved. Because of this no specific answers are available and only general consideration can be given to these aspects in this report.

Using the previously noted general rules as a basis, the recommendations for additional experimental work in the field of sandwich construction are given in Table I at the end of this report. The table includes recommendations for additional analytical work as well as for experimental work in order to develop design tools where these are needed. A discussion of the recommendations for each structural configuration and pertinent background information is given in the following sections

2

LOCAL INSTABILITY

2.1 INTRACELLULAR BUCKLING (Face Dimpling)

2.1.1 SANDWICH WITH HONEYCOMB CORE — Intracellular buckling for sandwich panels with honeycomb cores is analogous to flat-plate behavior and is calculated as a function of the sandwich cell size, faceplate thickness, Young's modulus of the material and a buckling coefficient, K. General practice has been to use a value of K = 2.0 for uniaxial compression, as noted on page 2-2, Reference 1, although this value does not represent a lower bound for the test data evaluated. This is not considered to be a serious problem, however, since dimpling can occur in several cells without causing catastrophic failure of the panel.

The test method generally used to obtain this buckling data is somewhat open to question, however, as not being quite representative of the actual situation. Test panels used for this are sandwich plates which employ a solid spruce core having a single circular hole drilled through it to represent the core cell. This type of specimen could be expected to give higher buckling values than those for a typical panel because of greater edge fixity for the intracellular plate.

On the basis of the above considerations, no recommendations are made here for additional experimental work in this area since present methods seem to provide sufficiently satisfactory results. It does follow, however, that efforts should be made to design a more realistic test specimen to obtain this data.

2.1.2 SANDWICH WITH CORRUGATED CORE – The design equations for intra-cellular buckling of sandwich panels with corrugated core presented in Reference 1 are based on plate buckling theories which have been well substantiated by tests in the past. Consequently, there appears to be no reason to doubt their adequacy at present or to recommend that additional experimental work be performed in this area.

2.2 FACE WRINKLING

2.2.1 SANDWICH WITH SOLID OR FOAM CORE – Solutions for critical face wrinkling stresses require knowledge of, or an assessment of, the value of the amplitude of the initial waviness in the facing for the particular panel. Since the value for this term which is appropriate to the particular panel or configuration is rarely known, typical panel data has been treated to develop a practical lower-bound parameter for use in initial calculations. Unfortunately, the data used in developing this lower bound does not appear to be representative of any realistic aerospace structures and, consequently, there is some question as to the validity of the recommended value of the parameter.

In view of the questionability of the present approach it would follow that a recommendation for additional experimental work is in order and such is the case.

However, development of realistic and representative designs poses special problems and since this stability consideration is rarely critical, this report recommends that the parameter given in the Reference 1 Manual be used for the initial design and that later checks be made for typical panels along with appropriate tests to insure their adequacy.

2.2.2 SANDWICH WITH HONEYCOMB CORE – The general comments and recommendations given above for sandwich panels with solid or foam core apply here also since the problem is very similar for both although the bounds of application vary somewhat.

2.3 SHEAR CRIMPING

This type of failure is generally representative of panels having low core shear modulus values. Extensive test data is available for this instability phenomenon and there is no reason to believe that more is needed at this time. However, this report recommends that the theoretical general instability solutions be extended to include the effects of face bending stiffnesses since taking these into account would allow better correlation with test data and provide for some increase in the allowable stresses.

3

FLAT PANELS

3.1 RECTANGULAR PLATES

As was noted in the Reference 1 Manual, extensive analytical and experimental work has been accomplished for this configuration and, thus, this report sees no need for additional efforts at this time, particularly for single loading conditions. Some small efforts in the area of combined loading conditions for both honeycomb and corrugated core sandwich panels is desirable, however.

3.2 CIRCULAR PLATES

No stability solutions for circular sandwich panels were uncovered in any of the searches made in the course of the preparation of the Reference 1 Manual. Likewise, no experimental data for any single or combined loading condition was discovered either. While this might presuppose strong recommendations for the development of both analytical and experimental data it is to be noted that this configuration is very rarely used in aerospace vehicle applications, particularly where instability problems may arise. Thus, while this report recommends some work in this area, it is not considered to be a vital necessity at this time.

3.3 PLATES WITH CUTOUTS

Due to the similarity of this situation with that to be covered in Section 8, discussions and recommendations for work in this area will be given in that Section.

4

CIRCULAR CYLINDERS

4.1 SINGLE LOADING CONDITIONS

4.1.1 CYLINDERS WITH HONEYCOMB CORES – Considerable analytical work and test data has been developed for honeycomb sandwich cylinders for most of the single loading conditions and additional work is in prospect for the near future. Despite this, there are several areas in which this report feels that additional data would be highly desirable. There is a need for more experimental work on sandwich cylinders with honeycomb cores whose shear moduli cause them to fall in the moderately-stiff-core and stiff-core regions. This data is particularly needed for the axial compression and pure bending single loading conditions. The same data is also needed for the external lateral pressure, torsion and transverse shear conditions although this need is not as pressing as for the first two conditions.

Some analytical and experimental work is also desirable to develop the behavior of cylinders with clamped ends for the axial compression and pure bending single loading conditions.

It is to be noted that while the previously described tests are desirable, they are not mandatory for the immediate future but should be kept in mind in the development of new programs.

4.1.2 CYLINDERS WITH CORRUGATED CORES – Very little analytical or experimental data was found for cylinders with corrugated cores and that was limited to the axial compression condition. It should be noted that the cylindrical configuration with the corrugations running in the direction of the axial loading is representative of typical aircraft plate-stringer construction, assuming a reasonable spacing of frames or bulkheads and can be treated in basically the same manner, analytically. This would also apply to the case of a pure bending loading condition but would not necessarily hold for the cases of external lateral pressure, torsion or transverse shear.

This report recommends that additional analytical development and experimental work be accomplished for cylinders with corrugated cores for those applications and loading conditions where this configuration appears structurally promising.

4.2 COMBINED LOADING CONDITIONS

4.2.1 CYLINDERS WITH HONEYCOMB CORES – Some data is available in the area of combined axial compression plus bending, however, additional experimental work is needed for other loading combinations in order to minimize the need for a conservative approach when designing for combined loading conditions.

4.2.2 CYLINDERS WITH CORRUGATED CORES – The same comments apply here as for corrugated core cylinders under single loading conditions except that there is even less experimental data available for the combined loading case. Thus, this report recommends that data be developed for representative configurations and combined loading conditions for those situations where this configuration appears promising.

5

TRUNCATED CIRCULAR CONES

5.1 SINGLE LOADING CONDITIONS

5.1.1 CONES WITH HONEYCOMB CORES – Very little experimental work has been done on truncated circular cones with honeycomb cores and this has been for axial compression only. Since these points when used in conjunction with the equivalent-cylinder analytical technique compared favorably with several cylinder test points it was decided that the equivalent-cylinder analogy was applicable and the truncated circular cone equations in the Reference 1 Manual were developed from the cylinder equations on this basis.

With this background information in mind, this report recommends that work be initiated in two areas for this general configuration. The first area is the accomplishment of experimental work to substantiate predicted cone behavior for a variety of single loading conditions. A second area for consideration is the development of a new theoretical approach for the analytical solution of this problem or a verification of the equivalent-cylinder method presently in use.

5.1.2 CONES WITH CORRUGATED CORES – Cones with corrugated cores enjoy approximately the same data situation as cylinders with corrugated cores. Because of this the data needs for the two cases are similar with both needing an appreciable amount of experimental work.

Additionally, analytical theory for cone behavior needs development and extension to cones of this configuration for use in design work. This is the same analytical development mentioned for cones with honeycomb core previously and quite possibly could follow from that work with some changes in approach and boundary conditions.

5.2 COMBINED LOADING CONDITIONS

5.2.1 CONES WITH HONEYCOMB CORES – The situation here is the same as that for the single loading case with, for practical purposes, no experimental data available for possible correlation. Thus, additional experimental work is needed here along with extension of analysis methods for design tools.

5.2.2 CONES WITH CORRUGATED CORES – The same situation holds here as for the honeycomb core, therefore, the same recommendations are made for work on this configuration.

6

DOME-SHAPED SHELLS

6.1 SINGLE LOADING CONDITIONS

This discussion will limit itself to the case of domes employing honeycomb core only since it is not very feasible to make domes using corrugated core because of the problems arising from curvature requirements on the corrugations.

While there is some test data available for the external pressure loading condition, more data is needed for stiff-core and moderately-stiff-core domes to enable a full description of the behavior of these specimens. The oretical and test work is also needed to account for the behavior of orthotropic cores when used in the fabrication of domes.

Certain other single loading conditions such as concentrated loads need analytical development and test correlation for use as design tools, also.

6.2 COMBINED LOADING CONDITIONS

Work on the Reference 1 Manual uncovered no analytical or experimental data for combined loading conditions on dome-shaped shells. Since there are foreseeable needs for data in this area this report recommends that some experimental work be performed for combined loadings, as well as single load conditions, on dome-shaped sandwich shells. Such analytical development or correlation required to transform this data into a useful design tool should also be accomplished.

7

SANDWICH SHELL SEGMENTS

7.1 CYLINDRICAL CURVED PANELS

The Reference 1 Structural Stability Manual proposed the use of the Schapitz criterion (Ref. 2) as a practical approach for the calculation of critical stresses in cylindrically curved panels. This approach has been successfully employed for non-sandwich skin panels in a number of cases and, as a consequence, was proposed as a reasonable approach for sandwich construction. The non-sandwich panel applications noted were limited to the case of axial compression and, therefore, the recommended approach, given in Reference 1, is limited to this loading condition although the definite possibility exists that this could be extended to other loading conditions.

Extensive experimental work is needed to test the reliability of the proposed approach. This applies not only to the axial compression case but also to other single and some combined loading cases. In the event that agreement between theory and experiment is poor, additional development of theoretical methods will be required to enable the data to be put to practical use.

It should be noted that while this report recommends additional work in this area the urgency of this effort is dependent upon the foreseeable requirements for panels of this configuration, as well as the needs to achieve minimum weight.

7.2 OTHER PANEL CONFIGURATIONS

No information is available for other panel configurations at this time. Since there are so many potential configurations and variations of loading conditions possible this report makes no recommendation for work in this area and suggests that each specific case be handled as it arises.

It should be noted, however, that the behavior of truncated cone segments might be obtained by analogy from cylindrical segment behavior by means of the equivalent-cylinder analytical technique which has been previously described for application to truncated cone behavior. Mention is made of this possiblity here since this segment configuration would appear to be among those most likely to be encountered in aerospace applications.

While the previously noted comments are basically directed toward segments employing honeycomb core they are equally applicable to corrugated core designs insofar as data needs are concerned.

8

SANDWICH SHELLS WITH CUTOUTS

The following comments on the problems encountered because of cutouts, as well as the definition of data needs, apply equally as well to flat sandwich panels (Section 3.3) as to sandwich shells. They also generally apply to both honeycomb and corrugated core configurations. Differences in recommendations will be noted in those cases where they may occur.

8.1 FRAMED CUTOUTS

Whether we like it or not, cutouts are a fact of structural life because of access and other requirements. Practical considerations, therefore, require that we develop analytical techniques and substantiate them with experimental data so that they are available for use in design as the need arises.

It is to be noted that generalized solutions exist for the case where the skin panels buckle and thus are able to carry only shear loads. This is not applicable to sandwich construction, however, because the panels have axial and/or bending stress capabilities in addition to shear.

This report in recommending that both analytical and experimental work be undertaken for this problem area recognizes the complexities of the problem and the number of variables involved. Among these considerations are the lateral moment of inertia requirements and relative areas of the framing members, the size of the cutout in relation to the overall size of the panel, length of pickup and feedout of the framing members on each side of the cutout and the possibilities of tapering these members. Prior to the definition of any program, studies should be made to set up the problem in terms of some number of dimension parameters which would enable answers to be extended to as wide a range of cases as possible. It should be noted that identification of these parameters might be most easily accomplished during the development of an analytical solution for the general case. Failure modes for such panels are another consideration with some situations being governed by local instability, others by general instability, and still others by a combination of both.

In any event, this report recommends that some experimental and analytical work be undertaken to develop useful solutions for this problem in the near future.

8.2 UNFRAMED CUTOUTS

This report recommends that all reasonable efforts be made to avoid unframed cutouts since they have all of the disadvantages of framed cutouts and, in addition, have a more serious local design problem because of the free edge. In any event, this approach should be restricted as much as possible because of potential problems of faceplate-core bond separation at the free edge due to damage and/or adhesive deterioration while in use.

It is quite possible that analytical tools developed for the framed cutout case could be adapted to this situation by letting the area and moments of inertia of the framing members go to zero, thus, the unframed cutout would represent the lower-bound value for the framed cutout case. Thus, this report makes no recommendation for work on this case beyond extension of the data developed for framed cases to this lower-bound cutoff.

9

INELASTIC BEHAVIOR OF PLATES AND SHELLS

9.1 SINGLE LOADING CONDITIONS

Comments and recommendations made in the following paragraphs for work on inelastic behavior are generally applicable to both honeycomb and corrugated core panels since this behavior is a function of the properties of the faceplate materials only. This also applies to both the single and combined loading conditions.

In general, the plasticity reduction factors used to account for inelastic behavior for single loading conditions are fairly well known and have been substantiated by test in the case of the more popular aerospace materials. This report, therefore, makes no recommendations for additional work in this area, at this time.

9.2 COMBINED LOADING CONDITIONS

Very little information is available on the inelastic stability of structures when subjected to combined loading conditions. The complexity of the problem and the variations in behavior between different materials has limited the development of theoretical solutions to handle this situation.

The materials problem arises from the fact that different materials behave in accordance with different theories of failure. However, one theory of failure, that of Hencky-von Mises, or the Octahedral Shear Stress Theory, seems to lend itself reasonably well to a description of the behavior of most aerospace materials and was proposed for use in the Reference 1 Manual. This report, however, recommends that additional experimental work be performed on this problem in order to substantiate the proposed approach for combined loading conditions.

Table I. Recommendations for Additional Experimental Work on Sandwich Construction

Section	Ref. Page	Report Recommendations					
		Experimental Needs			Analytical Needs		
		None	Some	Great	None	Some	Great
2 LOCAL INSTABILITY	3						
2.1 Intracellular Buckling	3	(HC), (CC)			(HC), (CC)		
2.2 Face Wrinkling	4	(HC), (CC)			(HC), (CC)		
2.3 Shear Crimping	5	(HC), (CC)			(HC), (CC)		
3 FLAT PANELS	6						
3.1 Rectangular Plates	6	(HC), (CC)			(HC), (CC)		
3.2 Circular Plates	6	(CC)	(HC)		(CC)	(HC)	
3.3 Plates With Cutouts	7		(CC)	(HC)		(CC)	(HC)
4 CIRCULAR CYLINDERS	8						
4.1 Single Loading Conditions	8		(HC), (CC)			(HC), (CC)	
4.2 Combined Loading Conditions	9		(HC), (CC)			(HC), (CC)	
5 TRUNCATED CIRCULAR CONES	11						
5.1 Single Loading Conditions	11		(HC), (CC)			(HC), (CC)	
5.2 Combined Loading Conditions	12		(HC), (CC)			(HC), (CC)	
6 DOME-SHAPED SHELLS	13						
6.1 Single Loading Conditions	13	(CC)	(HC)		(CC)	(HC)	
6.2 Combined Loading Conditions	13	(CC)	(HC)		(CC)	(HC)	
7 SANDWICH SHELL SEGMENTS	15						
7.1 Cylindrical Curved Panels	15	(CC)	(HC)		(CC)	(HC)	
7.2 Other Panel Configurations	16	(HC), (CC)			(HC), (CC)		
8 SANDWICH SHELLS WITH CUTOUTS	17						
8.1 Framed Cutouts	17		(CC)	(HC)		(CC)	(HC)
8.2 Unframed Cutouts	18	(HC), (CC)			(HC), (CC)		
9 INELASTIC BEHAVIOR OF PLATES AND SHELLS	20						
9.1 Single Loading Conditions	20	(HC), (CC)			(HC), (CC)		
9.2 Combined Loading Conditions	20		(HC), (CC)			(HC), (CC)	

NOTES: (HC) in column indicates level of need for honeycomb core panels.

(CC) in column indicates level of need for corrugated core panels.

REFERENCES

1 Sullins, R. T., Smith, G. W., and Spier, E. E., Manual for Structural Stability Analysis of Sandwich Plates and Shells, Prepared by the Convair Division of General Dynamics Corp. for the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, July 1969.

2 Schapitz, E., Festigkeitslehre für den Leichtbau, 2 Aufl., VDI-Verlag GmbH Düsseldorf, Copyright 1963.